Fundamental Aeronautics Program

Subsonic Rotary Wing Project

SRW Aeromechanics Overview/UH-60 Airloads Wind Tunnel Test Summary

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Agenda

• Aeromechanics Overview
  – Aeromechanics Objectives and Task Areas
  – Recent Accomplishments
  – Aeromechanics Near-Term Plans

• UH-60 Airloads Wind Tunnel Test Summary
Objectives

- Advance the understanding of phenomena in aerodynamics, dynamics, and active control of rotorcraft
- Develop and validate first-principles tools
- Acquire data for tool validation from small- and large-scale testing of existing and novel rotorcraft configurations
Aeromechanics Task Areas

- Aeromechanics Discipline organized into 6 interrelated task areas
  - CFD/CSD Tool Development and Applications
    - Structured
    - Unstructured
  - Icing
  - Active Rotors
  - Advanced Configurations
  - Rotor Aerodynamics and Interactions
  - Rotor Dynamics and Control
Recent Accomplishments

• CFD
  – Made significant improvements in structured and unstructured rotorcraft CFD methods (OVERFLOW and FUN3D)

• Icing
  – Continued development of high-fidelity icing analysis tools
  – Completed test of oscillating airfoil in Icing Research Tunnel (IRT)
  – Developed plans and began detailed preparations for subscale rotor test in IRT
Recent Accomplishments

• Active Rotors
  – Actuators developed, blade fabrication initiated, and test prep continuing for Active Twist Rotor (ATR) in Transonic Dynamics Tunnel (TDT)

• Advanced Configurations
  – Completed design and began fabrication of Tiltrotor Test Rig (TTR) and supporting equipment (balance calibration stand, model prep facility) for future testing in 40x80
Recent Accomplishments

• Rotor Aerodynamics and Interactions
  – Completed UH-60 Airloads rotor testing in NFAC 40x80 tunnel
  – Completed 1st phase of downwash/outwash hover testing
  – Completed testing and analysis of small-scale active flow control for fuselage drag reduction
  – Completed actuator development, fuselage fabrication, and test preparations for 14x22 test of active flow control fuselage with rotor
Aeromechanics Near-Term Plans

• Continue development and validation of structured and unstructured rotorcraft CFD methods
• Conduct icing test of sub-scale rotor in IRT
• Conduct Active Twist Rotor test in TDT
• Complete fabrication and development of TTR and conduct checkout test in 40x80
• Continue data evaluation/reduction and analysis validation with data from UH-60 Airloads wind tunnel test
• Downwash/outwash hover testing
• Conduct active flow control evaluation for fuselage in presence of rotor in 14x22
UH-60A Airloads Wind Tunnel Test Summary
Outline

• Test Objectives
• Test Description
• Test Phases and Conditions
• Sample Results
• Summary
• Near-Term Plans
Test Objectives

• Objectives
  – Acquire comprehensive set of validation-quality data (including airloads) to challenge SOA modeling and simulation tools
  – Acquire data to evaluate similarities/differences between small-scale wind tunnel, full-scale wind tunnel, and full-scale flight tests

• UH-60A Airloads Test successfully completed (May 2010) in USAF 40- by 80-Foot Wind Tunnel
Hardware

- Testing conducted in USAF National Full-Scale Aerodynamic Complex (NFAC) 40- by 80-Foot Wind Tunnel

- UH60A rotor system mounted on Large Rotor Test Apparatus (LRTA)
  - Rotor system uses same blades as used during 1993 flight testing, including pressure blade
  - Production UH-60 rotor system (hub, spindles, shaft extender, swashplate, pitch links)
  - LRTA provides rotor mount and calibrated rotor balance
Instrumentation

• 456 unique measurements acquired at each data point
• Key Instrumentation
  – Blade Pressures
    • 235 pressure transducers, mostly in chord-wise arrays at 9 radial stations
  – Rotor Performance
    • 28 LRTA balance gages to determine rotor forces and moments
  – Blade Structural Loads
    • 28 blade bending gages at 9 radial stations
  – Blade Root Motion Measurements
    • Two sets of 12 measurements each to measure blade root motion
Data Acquisition

• Two Primary Data Acquisition Systems
  – NFAC Data Acquisition System for most data
    • Standard wind tunnel system, 16-bit
    • Data acquired at 256 samples/rev
  – Rotor Mounted Data Acquisition and Transmission System (RMDATS) for blade pressures
    • New rotating data system designed for this test, 16-bit
    • Data acquired at 2048 samples/rev

RMDATS Rotating Subsystem
Independent Measurement Systems

- Three new systems developed specifically for this test
  - Blade Displacement System
    - Blade displacement and deformation
  - Retro-reflective Backward Oriented Schlieren (RBOS)
    - Tip vortex trajectory and orientation
  - Particle Image Velocimetry (PIV)
    - Flow velocities and vortex properties
Test Phases and Conditions

- 1-G Level Flight Sweeps
- Parametric Sweeps
- Airloads Flight Test Simulation
- DNW Wind Tunnel Test Simulation
- Slowed Rotor Testing
- PIV Testing
Test Phases and Conditions

• 1-G Level Flight Sweeps
  – Simulated 1-g level-flight speed sweeps (matching lift and propulsive force)
  – Advance ratio sweeps up to 0.4 for 3 lift levels

• Parametric Sweeps
  – Controlled variations of thrust, advance ratio, hover tip Mach number, and shaft angle across and beyond flight operating conditions
  – Thrust sweeps at 6 advance ratios, 3 tip Mach numbers, and 5 shaft angles
Test Phases and Conditions

• Airloads Flight Test Simulation
  – Matched conditions from Airloads Flight Test, including derivative points around the baseline to determine sensitivities
  – 3 flight conditions matched (c8425, c8525, c9020)

• DNW Wind Tunnel Test Simulation
  – Matched conditions from DNW small-scale test, including derivative points around baseline
  – 3 DNW conditions matched (11.24, 13.12, 13.20)
Test Phases and Conditions

• Slowed Rotor Testing
  – Parametric sweeps to evaluate non-conventional operating envelopes made possible by large reductions in rotor RPM
  – Collective sweeps at 3 hover tip Mach numbers and 3 shaft angles up to advance ratios as high as 1.0

• PIV Testing
  – Acquired detailed velocity data at selected test points to better understand flow physics
  – 11 different flight conditions
Sample Data – Stall Sweep

- Thrust vs. collective for collective pitch sweep (Mtip=0.625, mu=.30, alpha=0)
- Roll-off of thrust at high collectives indicative of stall
Sample Data – Stall Sweep

- Radial plots of section normal force (M2CN) at nominal and deep stall conditions (Mtip=0.625, mu=.30, alpha=0)
- Significant changes in lift distribution at stall

Nominal Thrust, $C_T/\sigma=0.08$

Deep Stall, $C_T/\sigma=0.125$
Sample Data – Stall Sweep

- Time history of section normal force (M2CN) at $r/R = 0.92$ for collective pitch sweep ($M_{tip}=0.625$, $\mu=.30$, $\alpha=0$)
- Lift stall evident at $\psi= 290$ deg and 340 deg at high collective
- Evidence of first stall cycle as low as 4.1 deg collective
Summary

- UH-60A Airloads Test successfully completed (May 2010) in NFAC 40x80 Ft Wind Tunnel
  - Measurements included blade pressures, rotor performance, blade loads, blade displacement, and rotor wake (using large-field Particle Image Velocimetry (PIV) and Retro-reflective Background Oriented Schlieren (RBOS))
  - Data acquired (including airloads) should provide excellent resource for validation of SOA modeling and simulation tools

- Data acquired over wide range of test conditions
  - Speed and thrust sweeps up to 175 kt and 32000 lb
  - Specified conditions from previous full-scale flight test and small-scale DNW wind tunnel test
  - Slowed-rotor simulation data at reduced RPM, achieving advance ratios up to 1.0
Summary

• Unique accomplishments
  – Most highly-instrumented rotor test ever conducted in the NFAC (including 235 rotating pressure transducers)
  – First test of production UH-60 rotor at high advance ratios (up to 1.0)
  – Successful acquisition of PIV data over the largest area ever attempted in NFAC (4 ft by 13 ft)
  – First ever use of an 8-camera, 4-quadrant photogrammetry technique to measure blade displacements

Laser for Particle Image Velocimetry

Retro-reflective Blade Displacement Targets
Near-Term Plans

• Prepare publications documenting test and techniques
  – 3 at May 2011 AHS Forum
    • Test overview
    • Slowed rotor
    • Analysis correlation
  – 2 at June 2011 AIAA meeting
    • PIV system development
    • Blade Displacement system development
• Continue data review, evaluation, and data reduction
• Prepare for external data release (documentation, data formatting)